National Aeronautics and Space Administration

Computing, Information and Communication Technologies Program
Information Technology Strategic Research Project
Intelligent Controls and Diagnostics Sub-Project

Intelligent Controls and Diagnostics for Propulsion Systems
UPN 302-05
FY04 Plan

Agreements:

____________________________________ ____________
Joseph J. Totah Date
Approve: Level III ICD Sub-Project Manager

____________________________________ ____________
Donald L. Simon Date
Submit: Level IV ICDPS Task Lead

1. Background

The Intelligent Controls and Diagnostics for Propulsion Systems (ICDPS) Task is part of the Intelligent Controls and Diagnostics (ICD) Sub-Project under the Information Technology Strategic Research (ITSR) Project of the Computing, Information and Communication Technologies (CICT) Program. This task directly contributes to the ICD sub-project goal to enable NASA's scientific research, space exploration, and aerospace technology missions with greater mission assurance, for less cost, and with increased science return through the development and use of advanced computing, information and communications technologies.

The ICDPS task envisions using advanced propulsion health management technologies. When integrated with intelligent control algorithms, the advanced health management technologies will allow aerospace propulsion systems to operate safely in the presence of subcomponent failures. The integration and implementation of ICDPS technologies will also enable engine component maintenance to be performed on an as needed basis instead of following a pre-set schedule. This approach will increase safety by reducing the risk of component failures between scheduled maintenance periods, and will help drastically reduce the cost of aerospace propulsion system maintenance.

The research effort supported by this element is managed and conducted at NASA Glenn Research Center. This plan provides a description of the ICDPS task and is the controlling document for project content and organization. The primary purpose of the plan is to:

- Establish task objectives and performance goals
- Establish task resource requirements and schedule
- Provide a tool for communicating effectively with implementing organizations

2. Objective

The objective of the Intelligent Controls and Diagnostics for Propulsion Systems (ICDPS) research effort is to develop and validate advanced control system and health monitoring technologies that are critical to enhancing the safety, reliability and operability of aerospace propulsion systems. The ICDPS research effort will directly contribute to the NASA goal of enabling a *safer, and more efficient air transportation system.* In addition, ICDPS developed technologies can meet *access to space* objectives through application to air-breathing propulsion systems targeted for space access.

For FY04, ICDPS will focus on two sub-tasks - Intelligent Life Extending Control (ILEC), and intelligent Data Fusion (DF) for propulsion health management. The focus of the ICDPS effort will be to develop these technologies such that, when integrated into a system, the technologies will lead to a distributed control and health management system for aerospace propulsion systems that is safe and robust to engine component failures and degradation. Previous ICDPS work in the areas of Photonic Sensors and Systems (PSS) and High Temperature Electronics (HTE) concluded in FY02.

Although the technologies undergoing development in this task are being applied to aircraft propulsion systems, these technologies are generic in nature and with appropriate modification can be applied to other systems of interest to NASA such as air-breathing access to space propulsion systems, rocket propulsion systems, and land-based turbine driven vehicles such as autonomous rovers.

3. Technical Approach

The emphasis of this task is to develop and validate integrated control and health management design technologies that will help in extending operating life of critical engine components for air-breathing propulsion systems and will improve diagnostics and prognostics capability to better identify engine component failures and degradation. The two technology efforts under this task are described below.

3.1 Intelligent Life Extending Control

With the recent emphasis on reducing engine operating cost, the industry is interested in developing technologies that will allow the engine and its components to operate longer, thus increasing the time between engine overhauls. The way an engine is controlled has a severe impact on the life of the components. Typically, the propulsion system control design engineer attempts to get the maximum performance out of the system while maintaining safe operation. Recent studies have shown that small changes in engine operating parameters, such as turbine inlet temperature, can have a significant impact on the damage accrued by engine components while having no noticeable change in engine performance.

The Life Extending Control sub-task consists of two separate efforts – one with a near term focus and the other with a long term pay-off potential. The near term focus program was conducted in partnership with Scientific Monitoring Inc., a small business, and Honeywell Aerospace. The objective of this effort was to develop and demonstrate control strategies for a short haul aircraft engine that will result in extending the on-wing life of the engine while using the current sensor set and life model assumptions. This effort was completed in FY01 with real-time engine control hardware in the loop demonstration of engine control laws that have the potential to reduce thermal fatigue damage to the high speed turbine by 20% during engine acceleration from idle to max power that is typical of take-off operation. This damage reduction is achieved by an intelligent management of the acceleration command for the high speed rotor such that the acceleration command is reduced at a critical juncture where the temperature gradients on the turbine blades are the highest. This damage reduction is achieved for a very small increase in rise time for achieving maximum thrust. This increase in rise time for thrust is within the specified engine performance requirements.

For the long term effort, a one-year study was initiated in partnership with General Electric Aircraft Engines to explore all potential schemes to extend engine life. This study identified that the maximum engine life extension benefit can be achieved by tighter control of the clearance for the high speed turbine. In FY02 and future years, the effort with GE will focus on developing innovative adaptive clearance control that can compensate for the typical deterioration experienced by turbines in field operation. Currently the clearance control consists of an open-loop scheduling of the turbine cooling flow based on pilot throttle commands. The technical approach under this effort will consist of developing accurate estimation techniques for turbine clearance, and using this estimate in the feedback loop to control the cooling flow to the turbine. The current plan is to develop the technology to a TRL (Technology Readiness Level) of 4 by demonstrating the technology in real time simulation with engine controller hardware in the loop.

Another important aspect of the long term research in developing intelligent life extension control technologies is the joint effort between NASA in-house researchers and the University of Texas San Antonio (a Hispanic Serving Institution). Under the in-house effort a SIMULINK based simulation of an advanced aircraft engine was developed based on a Fortran simulation provided by GE, and under the University of Texas San Antonio effort progress was made on development of stochastic models for determining damage to engine components. In FY03 this effort successfully completed the Level II milestone 8.6.1 of conducting an engine simulation demonstration of smart life extending control using stochastic based life models.

3.2 Data Fusion for Propulsion Health Management

There is currently a tremendous amount of data available on the performance and condition of an aircraft turbine engine. This data comes from various onboard sensors, maintenance logs, and operating histories. In addition, there are various efforts underway to develop advanced diagnostic and prognostic sensors. These sensors will be able to measure engine vibration and other quantities that are indicative of component degradation and failure. The objective of the data fusion effort is to develop intelligent algorithms to integrate the engine data available from multiple sources and maximize the beneficial information extracted regarding system and component health. This task is being conducted in partnership with Pratt & Whitney with a focus towards integrating the information obtained from flight testing of advanced diagnostic and prognostic sensors, under the NASA Dryden sponsored C-17 flight test program, with the advanced algorithms.

In FY01, a preliminary study was completed to define an architecture and approach for data fusion within an advanced propulsion Prognostics and Health Management System. Foreign Object Damage (FOD) and actuator gas path faults were identified as two potential faults that manifest themselves in multiple sensor measurements, and a novelty based anomaly detection approach was identified as a potential technology for determining anomalous events that do not correspond to nominal or known engine faults. In FY02 and FY03 the effort focused on further development of the neural network based anomaly detection approach, the development of an empirical lubrication system model, and the development of a Matlab/Simulink based data alignment module for fusing data collected at various sample rates. These elements of the overall data fusion architecture were developed and demonstrated using available flight test data collected from the C-17 T1 aircraft. Additionally an in-house effort by NASA researchers has been initiated to further develop stochastic based data fusion technologies.

In FY04-05 additional enhancements to the data fusion architecture and technology will occur. An intermediate data fusion architecture demonstration will occur in the first quarter of fiscal year 2004, and a final demonstration will occur in the first quarter of fiscal year 2005. Both of these demonstrations will use available C-17 T1 aircraft flight data.

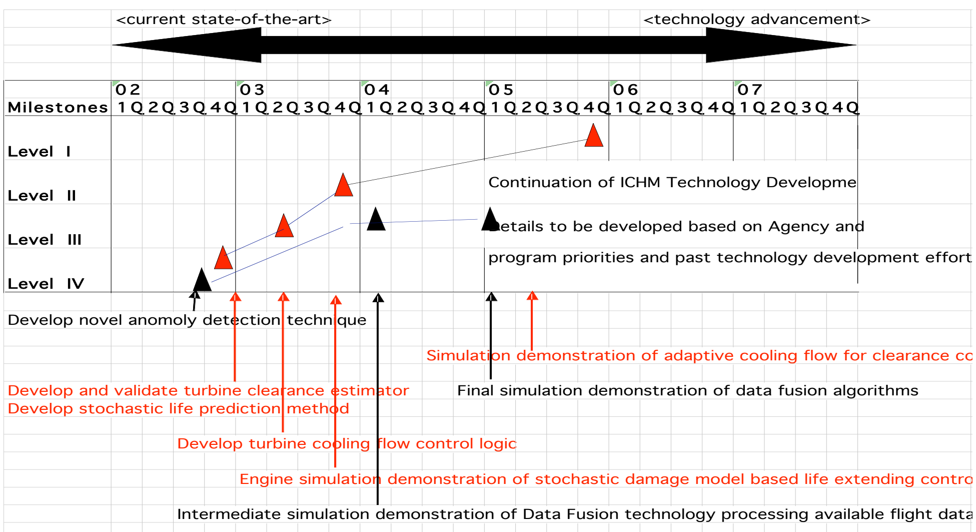
4. Milestones

PCA 8 *Project*/Sub-Project Milestones	**Due Date**	**Metrics**
8.6 Demonstration of propulsion health management technologies for engine performance enhancement and component health and safety monitoring.	*Sep-06*	*(1) An adaptive control system for turbine casing cooling flow to accommodate the effect of engine degradation on turbine clearance. Maintain design efficiency of the turbine as the engine degrades by maintaining the clearances to the design level, resulting in increased engine life due to reduction in rate of exhaust gas temperature degradation and consistent performance over the engine life.* *(2) Development of HealthWatch III (HW-3) including a programmable data acquisition system and the ability to sample and store high-speed data in operation. A health monitoring system for integrated real-time sampling of both vibration and oil-debris signals for advanced damage detection of incipient component degradation.*
8.6.1 Engine simulation demonstration of smart life extending control using stochastic based life models.	Sep-03	The engine control will adapt to current engine condition with the objective to minimize future damage accumulation. Improved engine control will result in increased engine on-wing life and reduction in maintenance cost.
8.6.4 Post flight test analysis, reporting, and outreach.	Sep-06	Final report on flight test demonstrations, and print/multi-media development for educational outreach and external affair. NASA Technical Memorandum or NASA Technical Paper documenting the approach, methodology, and experimental/experimental results that can be used as a substantive reference upon which future work can build upon. A conference paper and/or journal article in a relevant professional forum will also be presented so that the results can be shared with the technical community at large.

Task-Level Milestones:

- (4QFY03 Level II milestone 8.6.1) Engine simulation demonstration of smart life extending control using stochastic based life models. (*Completed on schedule*)
- (1QFY04 – Level III milestone) Intermediate simulation demonstration of Data Fusion architecture using available C-17 T1 flight data
- (1QFY05 – Level III milestone) Final simulation demonstration of Data Fusion architecture using available C-17 T1 flight data
- (4QFY05 – Supports Level I Milestone 8.6) An adaptive control system for turbine casing cooling flow to accommodate the effect of engine degradation on turbine clearance.

5. Schedule



6. Resources / Budget

Labor:

2.50 FTE
0.00 WYE

Procurement (excluding labor):

$0.243M Procurement

7. Management Approach

<u>Deliverables (FY 2004)</u>:

- Research Technical Paper documenting engine simulation demonstration of smart life extending control using stochastic based life models compliant with NASA Glenn Research Center publication procedure GRC-P 5500.005.

- Simulation / demonstration of technologies.
- Physical / experimental data acquisition and/or technology validation.

Environment / Equipment:
- ICDPS NASA in-house research will take place in the Controls and Dynamics Technology Branch (CDTB) using available desktop computers and/or the CDTB simulation laboratory.

Compliance with Standards and Codes:
- GRC-P 5500.005 5500 Division Report Review and Publication
- GRC-P 5500.001 Initiating and Performing Research

Applicable Quality System Procedures and Work Instructions:

- GRC-P 5500.003 Answering Technology Inquiries
- GRC-P 5500.004 Disseminating New Technology
- GRC-P 5500.005 Record Keeping for Research Activities

Process Monitoring Methods/Procedures:
- Performed to satisfy all Level I business requirements, described below:

Type	**Frequency**	**Purpose**	**Reporting By**	**Content/Format**	**Comments**
Technical Highlights	Weekly	Status updates and/or highlights	L4 Task Leads and Technical POCs	Informal text of monthly progress - indicate “None” for negative replies *e-mail text; web-site entry*	Unless significant progress is reported, can be brief
Quarterly Progress	Quarterly	Program Management Council (PMC)	L2 Managers	Text (and accompanying graphic, if any) of quarterly progress towards L1/L2 milestones *e-mail text; electronic copy of graphic; web site entry (under development)*	Progress towards all active L2/L3 milestones should be reported
Technical Highlights	Quarterly	Program advocacy and reviews	L2 Managers	One page text (Bullets: Objective, Background, Accomplishment, Future Plans) and one page graphic *e-mail text; electronic copy of graphic; web site entry (under development)*	Technical Highlights are used to promote the CICT Program and represent significant accomplishments
Milestone Summaries	Milestone due dates or completion	Program advocacy and reviews	L2 Managers	Detail description of milestone accomplishments relative to goals and success metrics. Background material including graphics, technical reports, publications, etc. *e-mail text, electronic copies of graphics, hardcopies of reports*	
Budget and Workforce Tracking	Monthly (5th working day of each month)	Status reports to ITSRPO and CFO	Center POCs for resource management	Spreadsheets, graphs at the 5-digit level. Include variance explanation for +/- 10% variances *e-mail text; electronic copy of graphs; web site entry (under development)*	Planned vs. actual commitments obligations and accruals at 5-digit level. Planned vs. actual CS and SSC workforce.
ATAC Sub-committee Reviews	Annual	To review and provide advice on research efforts	L1, L2, and L3 Managers and Technical POC’s	Program, project, and sub-project plan on-site review on status, approach, and technical accomplishments	
LCPMC	Annual	To review	L1 and L2	Program and Project tracking of	

		status, budget, and milestones	Managers	budget and milestones	